MANUAL FOR MANGROVE MONITORING IN THE PACIFIC ISLANDS REGION

Monitoring Changes in Mangrove Condition

DRAFT
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For

Secretariat of the Pacific Regional Environment Program
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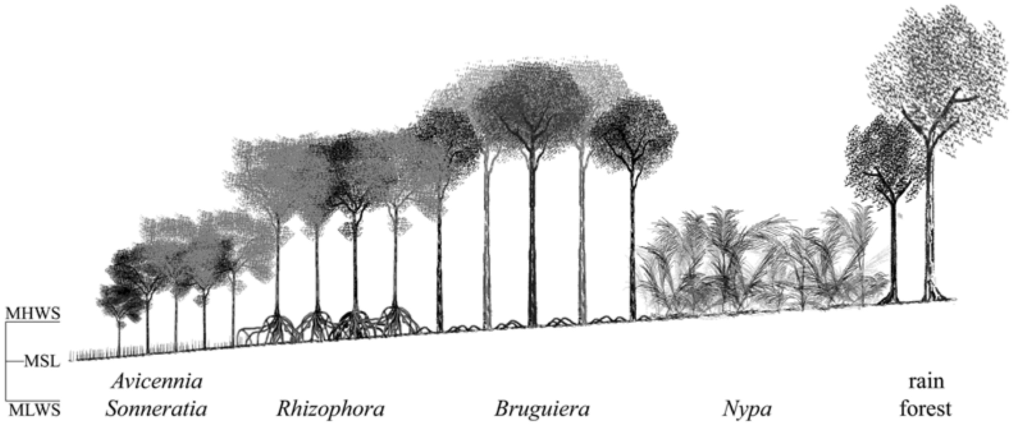
Introduction

Mangrove Monitoring – Identification of Need

Mangrove forests occur on low energy, sedimentary shorelines of the tropics, between mean tide and high tide elevations. Mangrove trees have physiological and morphological adaptations to the environmental stresses of their intertidal habitat, of high salinity, low oxygen, poor nutrient availability and substrate mobility. These cause the different mangrove species to prefer a particular elevation between mean tide and high tide, True mangrove species occur exclusively in this saline wetland environment, with adaptations such as aerial roots, halophytic strategies, vivipary and water conservation.



Mangrove zones from mean tide to high tide typical of PNG and the Solomons.

Conversion of mangrove area to other uses, Northern Viti Levu, Fiji

In the last few decades, large areas of mangrove forests have been destroyed by overexploitation and conversion to other uses. The cumulative effects of natural and human pressures make mangrove wetlands one of the most threatened natural communities worldwide, with roughly 50% of the global area lost since 1900, and 35% of the global area lost in the past two decades. Human activities still continue to be the major cause of degradation and loss of mangrove ecosystems in all parts of the world, including the Pacific Islands region. Monitoring will measure mangrove extent and condition, and allow mangrove ecosystems to be conserved and managed sustainably to maintain their environmental, ecological, and socioeconomic benefits.

Mangrove ecosystems are also expected to show a response to climate change and sea-level rise. The main impacts of climate change that can be expected to affect mangrove ecosystems are sea level rise and changes in precipitation, primarily through altered sediment budgets, and temperature rise and the direct effects of higher levels of atmospheric carbon dioxide changing productivity and ranges of species. The nature of this response is multi-faceted, and will be subject to factors of environmental setting. Several expert groups have identified the need for a monitoring system of mangrove response to climate change (IOC, 1990; IOC, 1991; UNEP/UNESCO, 1993; UNEP, 1994). A monitoring program would help identify how the Pacific region mangroves respond to relative sea-level rise.


Mangrove dieback with rising sea-level, Bermuda.

In the Pacific Regional Wetlands Action Plan (SPREP, 1999) endorsed by the 26 member countries, two actions identify the need for scientific monitoring of mangroves of the region. This would assess mangrove extent, community structure, status and health. Since 1999, mangroves of the region have come under increasing pressure from coastal development, and the sea-level rise projections have increased (IPCC, 2007).

This monitoring protocol adapts internationally accepted mangrove monitoring methods to Pacific Island settings, and gives guidance of three levels of intensity of monitoring. The methods will generate baseline survey data that can be used to monitor changes and make comparisons across mangrove areas in the wider Pacific.

The objectives of this monitoring program are:

1. To detect and quantify major changes through time in the community structure and health of mangroves in the Pacific Island Region using biological and physical parameters.

2. To develop a centralised database system for mangrove monitoring for use by all.

This will be a tool in improving mangrove management, augmenting or restoring a mangrove conservation ethic, and reversal of trends in human-caused degredation of mangroves.

1.4. Mangrove functions and values

Mangrove ecosystems can be a useful buffer between the land and the sea. They act as a sink for sediments, nutrients and other contaminants to maintain coastal water quality, and so are linked with maintaining the health and natural functioning of coral reef and seagrass beds offshore. They also protect the land from marine inundation during storms and sea-level rise.

The mangrove areas are important for maintenance of coastal water quality. Mangroves acts as a sink for nutrient-rich runoff from settlements, protecting lagoons from eutrophication. The mangrove area acts as a sink for sediment released during land development, maintaining the clarity of lagoon or nearshore waters (which is good for coral growth). The mangrove area also protects the inland land use activities from waves and wind damage during storms.

Fish-trap in the mangrove surrounded Fanga 'Uta Lagoon, Tongatapu, Tonga.

Mangroves have been shown to be important fish habitats, with function as a fish nursery. Mangroves sustain a foodchain within the mangrove habitat, and tidal export of mangrove material supports offshore foodchains. Many species of fishes, crustaceans, molluscs, amphibians, reptiles are found in mangroves.

Mangroves can also be useful resources for education and ecotourism. Boardwalks with interpretive signs are popular with visitors. Mangroves and their associated flora and fauna can also be accessed and enjoyed by visitors from their seaward side such as via viewing platforms, outrigger canoe tours, boat trips, and sea kayaking tours.

Canoe tour through Enepein mangrove swamp, Pohnpei, Federated States of Micronesia

1.3. Global and Regional Context

The world mangrove area is estimated at 181,000 km^2 (Spalding et al., 1997). In the Pacific Islands region, total mangrove area is about 4,000 km^2, or only 2% of the world's mangroves, with the largest areas in Papua New Guinea, Solomon Islands, Fiji and New Caledonia. While the mangrove area in some Pacific Island countries is relatively small, each species mixture is unique in the Pacific Islands (adapted from Ellison, 1995, Table 1), and the mangroves have important values to island communities.

There are 34 species of mangroves and 3 hybrids in the Pacific Islands. These are of the Indo-Malayan assemblage, and decline in diversity from west to east across the Pacific, reaching a present limit at the Marshall Islands in the North Pacific. Mangroves are introduced in Hawaii and maybe Tahiti, and possibly some locations in the Marshalls. The mangrove area of the Pacific islands is small in global terms, but each island group has a different mix of mangrove community structure, and the mangroves provide valued site-specific function

Table 1. Mangrove areas and species diversity in the Pacific islands (from Ellison, 1995).

Pacific Island Country (by Longitude)	Mangrove species	Mangrove Area (ha)
Palau	13	4,708
FSM	14	8,564
Papua New Guinea	33 (2)	550,942
Guam	11	70
N. Mariana Islands	5	5
Solomon Islands	25	52,550
New Caledonia	14 (2)	20,250
Vanuatu	13	2,430
Marshall Islands	5	?
Nauru	2	1
Kiribati	4	258
Tuvalu	2	40
Wallis & Futuna	0	0
Fiji	8 (1)	41,000
Tonga	8	1,000
Samoa	3	1,270
American Samoa	3	52
Niue	1	0
Tokelau	0	0
Cook Islands	0	0
French Polynesia	1	?
Pitcairn	0	0
TOTAL	34 (3)	343,998

(Hybrids are in brackets)

	Hertieira littoralis	*Aegiceras corniculatum*	*Sonneratia alba*	*Sonneratia caseolaris*	*Sonneratia x gulgngai*	*Osbornia octodonta*	*Lumnitzera littorea*	*Rhizophora apiculata*	*Rhizophora stylosa*	*Rhizophora x lamarkii*	*Rhizophora mucronata*	*Rhizophora samoensis*	*Rhizophora x selala*	*Bruguiera gymnorrhiza*	*Bruguera parviflora*	*Bruguiera sexangula*	*Ceriops tagal*	*Excoecaria agallocha*	*Xylocarpus granatum*	*Xylocarpus moluccensis*	*Avicennia alba*	*Avicennia marina*	*Scyphiphora hyrophyllacea*	*Nypa friticans*
PNG*	■	■	■	■	■	■	■	■	■	■	■			■	■	■	■	■	■	■	■	■	■	■
Solomons	■	■	■	■	■	■	■	■	■	■	■			■	■	■	■	■	■	■	■	■	■	■
Vanuatu	■		■	■			■	■	■		■			■	■		■	■	■	■		■		
Palau	■		■				■	■			■			■			■	■	■	■		■	■	■
FSM	■		■				■	■	■		■			■			■	■	■	■		■	■	■
NCaledonia	■		■				■	■	■	■	■	■	■	■	■		■	■	■	■		■	■	
N Marianas									■					■				■						
Nauru									■					■										
Guam	■						■	■	■		■			■				■		■	■	■		■
Fiji	■						■		■			■	■	■				■	■	■				
Tonga	■						■					■		■				■	■	■				
Samoa												■		■						■				
Am Samoa												■		■						■				
Kiribati			■				■		■					■										
Marshalls			■				■				■			■										
Tuvalu							■		■															
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Table 2, Mangrove species present in each Pacific Island group. *See Table 3 for additional mangrove species that occur in PNG alone of the Pacific Islands

Table 3. Mangrove species that occur in PNG alone of the Pacific Islands

	Aegialitis annulata	*Camptostemon schultzii*	*Sonneratia ovata*	*Sonneratia lanceolata*	*Lumnitzera racemosa*	*Bruguiera cylindrica*	*Bruguiera exaristata*	*Bruguiera hainesii*	*Ceriops decandra*	*Kandelia candel*	*Xylocarpus mekongensis*	*Avicennia officinalis*	*Avicennia rumphiana*
PNG	■	■	■	■	■	■	■	■	■	■	■	■	■

Monitoring techniques

Level 1- Transect based survey recording mangrove locations, species zones, mangrove condition and identifying pressures. Level 1 is quick to do, and is a suitable exercise for capacity building with community groups.

Level 2- Vegetation plots in each zone recording community structure, height and diameter of trees, density of seedlings. Level 2 takes about a day per transect, and is better carried out by project staff, though can be done with community groups assisting.

Level 3- Sedimentation monitoring and litter productivity. These techniques take longer to carry out but can give good information on mangrove health and sedimentation trends.

The three different levels build upon each other, hence rather than being alternatives, you can start with level 1, then add in level 2 as capacity and experience builds in the team or country.

Level 1 Monitoring

Level 1 monitoring establishes what mangrove resources are present and what condition they are in.

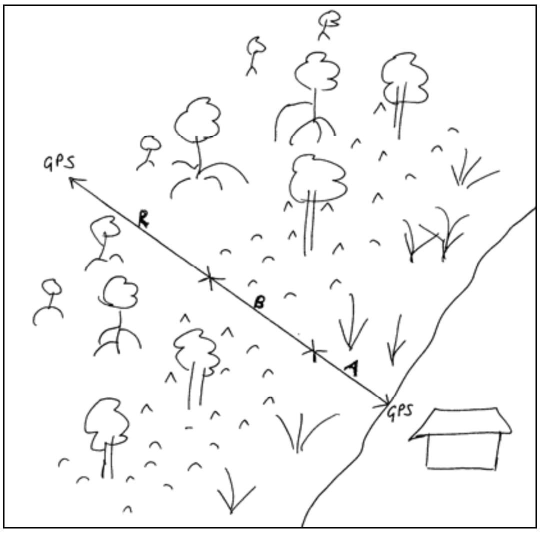
Mangrove margin at Ha'ateiho, Tongatapu. (Picture: Commonwealth of Australia, 1990). Note two shore parallel zones in the mangroves shown in darker and paler green, and much clearance of the landward zone on the right hand side of the picture.

Pre field work planning and preparation

a) Determine the extent of the mangrove forest using the most recent aerial photographs.
b) Examine the aerial photograph. Can you identify any species zones in the mangroves? Can you spot any mangrove disturbance, such as gaps and paths? Identify changes in areas of predominant forest types (mangrove zones).

c) Photocopy the aerial photograph. Mark the vegetation zones on the photocopy. Include a scale and identify the direction of North. This is the copy that you will take into the field to accurately check the types and positions of the zones, called ground truthing.
d) Mark on the photocopy of the aerial photograph several transects 90° to the coastline, making sure to sample the area sufficiently so that you can rely on any conclusions that you draw from the data. If practical, include at least one transect for every 100 m length of mangrove along the coast, with one transect passing through the apparent centre of the mangrove area or bay. Number the transects from 1 to the final transect, from West to East or from North to South depending on the orientation of your site.
e) Mark on the photocopy of the aerial photograph any prominent landmarks or geomorphic features such as beachrock or creek channels that will help you to identify your transect lines when you are in the field.
g) Make sure you have all field equipment needed.

Equipment required: Pencil and copies of data sheet, clip board, 50 m fibreglass tape (open reel is best in mangrove mud), magnetic compass, photocopy of aerial photo of area, GPS, brightly coloured flagging tape.



Transect through mangrove swamp with three zones.

Go to your first transect location. Your start point for the transect should be just above the high tide mark. For the purposes of this monitoring protocol, you are in a mangrove wetland when there are even a few mangrove trees present. Use major features visible on the aerial photograph to determine where this point and your transect line is.

Identify the transect start position using the GPS, write this position onto your data sheet. Take notes which will help you relocate this position if you do not have a GPS such as marking the point with flagging tape.

Fill out all the information required on the data sheet. Walk the transect lines into the forest using a 100m fiberglass tape. Use a hand bearing compass to ensure that transect is perpendicular to the shoreline. Note which species are in a zone, which species are abundant, and which species are rare. Measure width of each zone (m).

In the centre of each mangrove zone, assess the degree of human impact and note type for each zone (Tables 4 and 5).

Assess the degree of impact in an area with a 15 m radius around you. Impact is assessed on a scale from 0 to 5 where 0 is no impact and 5 is severely impacted. See Table 4. Do this by looking up at the forest canopy- notice the average height of trees, and assess how many are at that level, whether they touch and overlap (code 0) or whether there are gaps between them.

Table 4 Codes used to record the impact of pressure on mangrove ecosystems.

Code	**Impact**	**% Cover Canopy**	**Example**
0	No Impact	96-100	Even canopy of trees. No gaps. No evidence of human interference.
1	Slight Impact	76-95	Canopy of trees fairly continuous but some gaps. Some regrowth. Isolated cutting/ stripping of trees or some evidence of pigs digging up saplings.
2	Moderate Impact	51-75	Broken canopy of trees with lower regrowth and recruitment areas. Some trees cut and stripped.
3	Rather High Impact	31-50	Tree canopy is uneven, the majority of the area is not showing regrowth and there is bare mud.
4	High Impact	11-30	Only a few trees remain at canopy height. Extensive clearance and some recruitment, large areas of bare mud
5	Severe Impact	0-10	Extensive clearance to bare mud, little recruitment, few trees remain alive

Then look around and work out why any impact is occurring. Remember that in some areas mangroves are naturally spaced and stunted. Record an index of "human pressure" within the area with a 15 m radius around you. The impact may be direct, indirect, or both, record any activities such as piggeries, garbage dumps, illegal cutting, storm damage, etc. Codes for the types of impacts are shown in Table 5.

Table 5 Codes used to describe the type of impact at a site (Adapted from Table 3.5 English et al. 1997).

Code	Type of Impact
CO	Infrastructure including, piggeries, garbage dumps, developments
ER	Erosion- shown by uneven mud surfaces or little scarps/ cliffs
EC/BS	Extensive cutting or Bark stripping (for tannins/ dyes)
MI	Mining activities such as sand collection
MU	Multiple impact. Note codes of multiple impacts in Remarks.
OT	Others eg. pig foraging. Note this in remarks.


Storm damage to *Rhizophora* at Masefau, American Samoa.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Bark stripped from *Bruguiera* for tannin use, Viti Levu, Fiji.

When you reach the seaward edge, record the GPS position here. Make notes on the seaward edge, as if the mangroves are healthy there will be recruitment here, small trees growing seaward of the main trees. Note mangrove seedlings can reach 60 cm using their seed resources alone, and then may die if conditions are unsuitable. If the mangrove edge is under some stress, then the trees will be open with little recruitment.

Look at the sediment surface at the seaward edge, if there are small cliffs or scarps in the sediment, this indicates erosion. Note theis and the extent of it under impacts.

Open mangrove margin with no recruitment, Pala lagoon, American Samoa.


Erosion of sediment at an *Avicennia* seaward margin, southern New Guniea.

Level 1 Mangrove Monitoring Field Data Sheet

Use a new data form for each transect vegetation zone

Date : _______ Time: _______ Site name: ___________

Transect number: ______ Description of start point ___________

Transect landward start Latitude : ________.

Longitude : _______

Description

Compass heading 90 degrees from coastline: _____________

Zone	Species present	Width (m)	Degree of Impact	Impact type
1				
2				
3				
4				
5				

Transect seaward end Latitude : ________.

Longitude : _______

Notes on seaward edge: (ie eroding, accreting with seedlings?

Remarks (include names of observers/team):

Level 2 Monitoring- Permanent plots

Equipment required: All listed under level 1. In addition, small short metric tape measure (ie sewing tape measure) with mm intervals marked to measure tree girth, numbered aluminium tree tags (ask about these at a Forestry Department), aluminium nails, hammers, mig wire, wire cutters, callipers if available to measure girth of small trees, extending surveyors staff for measuring height (can be borrowed from a survey department).

Field work: In the mangroves

Identify one plot location in the centre of each mangrove zone, selecting an area for each plot that appears to be characteristic of the zone based on the aerial photo and your knowledge of the site. Locate the plot along one of the site's transects. Avoid unique spots, such as next to a tidal creek or development. Each plot should be 10 m x 10 m in dimensions, though practically if the trees are very dense you can reduce this to 5 x 5 m, or very large then increase to 20 x 20 m. While one plot per zone is the minimum, you can add replicates (other adjacent plots) to improve your monitoring rigour, as greater sample size gives more robust statistical analysis.


Measuring tree height in the mangroves of Ailuk atoll, Marshall Islands.

Mark the corners of each plot with a flagging tape, and use the GPS to identify the location of each corner. For each tree in the plot, hammer in a tag at around 1.3 m high using a stainless steel nail and numbered tag on each tree within the plot. Choose a section of the trunk that is blemish free, and below any major branches. On *Rhizophora*, measure above where the roots converge and below where the branches spread. Measure the circumference of the tree 2 cm above the height where you installed the tag, as this avoids any scarring when remeasured later. If the tree is too small to take a nail, then put the tag on a loop of stainless steel wire (i.e. mig wire), and clasp this onto a suitable low branch. Measure the circumference 2 cm below the nail ie below the branch. The diameter can be calculated later from the circumference measurement (diameter = circumference divided by phi). Within each permanent plot, tag saplings with a tree tag on a ring of mig wire, leave enough slack for growth. Measure the height and diameter.

Make a sketch map of where each of the numbered trees are located in the permanent plot, marking the direction of North on the sketch.

<u>Young *Rhizophora* tagged with mig wire.</u>

Level 2 Mangrove Monitoring: Data sheet for each permanent plot

Tag number	Species	Diameter	Height	Remarks

List the names of the data collectors and any other relevant information about the site such as activities observed, other species observed and the distance along your transect.

Level 2 Mangrove Monitoring:

Sketch map of mangrove plot showing approximate location of each tagged tree.

Give a North arrow, a scale, and show any features like fallen trees

Level 3 Monitoring: Litter productivity and sedimentation monitoring

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1. Litter productivity

Litter means the productive fall from a forest, not garbage in this context! Data on litter fall should be collected for a minimum of a year, to show vegetative production (grams production per square meter of mangrove forest) and phenology (the timing of flowering and fruiting).

Equipment required: for each litter catcher, 4 m of 4 cm diameter pvc pipe, 4 pvc corners to fit, glue to stick these together into a square, about 2 m^2 of shadecloth, small plastic ratchet clips, rope to hang catcher in trees, plastic bags and marker pen for the catch, drying oven, 2 decimal place balance.

Fieldwork

In each permanent plot, hang 1 m^2 litter catchers in the trees above the reach of tides, minimum three per plot. Empty these monthly into to a plastic bag.

Laboratory work

Place each sample in a large oven proof tray, and dry the catch of each in an oven at 60°C for 2 days, then sort into leaves, fruit, flowers, wood and weigh each component.

Litter catchers hung in *Rhizophora* forest.

2. Sedimentation monitoring

Equipment required: Narrow PVC pipes or other narrow plastic building material (nylon rod is suitable), 50 cm long – determine how many you need based on the estimated combined length of your transects, where you will install one PVC pipe every 10 m along each transect. Small level. Hand-held tape measure.

Fieldwork

Install one sedimentation stake every 10 m along the transect, starting with the first stake 10 m from the landward start of the transect. Select a location unlikely to be stepped on. Push each stake into the wetland surface so that only 10-15 cm of the pipe remains protruding from the sediment surface. Place a small level on top of the sedimentation stake, and measure the elevation 10 cm horizontal from the top of each sedimentation stake to the mangrove sediment surface in mm, using a level to ensure you are keeping horizontal with the top of the pipe. Do this at each pipe facing the same direction, best to face seaward along the transect magnetic bearing. You measure the elevation 10 cm away from the pipe to avoid any distortion to the sediment surface caused by the presence of the pipe, such as scouring around the base of the pipe.

Measuring a mangrove sedimentation stake, American Samoa

Data recording

This section will be developed in conjunction with the SPREP GIS appointment.

A spreadsheet will be created for each mangrove site. Enter the data from your field data sheets, where there is one data sheet for each transect's vegetation zone, into the database. After inputing your data into the computer, check your field data sheet against the data you entered in the computer to try to catch any mistakes made during the data entry.

Example 1: Suva, Fiji

Mangrove Monitoring Field Data Sheet

Date : _16.03.07_ Time: _0950_ Site name: Muanikau at R.T. Kamarusi Park, Suva, Fiji
Transect number: _1_____ Vegetation zone (dominant tree species): Rhizophora

Transect landward start Latitude :18^o 09' 26.4"S.
Longitude : 178^o 26' 40.4"E

Description

Compass heading 90 degrees from coastline: 120^o

Zone	Species present	Width (m)	Degree of Impact	Impact type
1	Rhizophora samoensis	19.6	Moderate	garbage
2	Bruguiera gymnorrhiza	15.0	Highly impacted	Bark stripping, garbage, recently introduced sediment burying roots
3	R. samoensis, R. stylosa	35.6	Moderately impacted	Large woody debris, garbage

Transect seaward end Latitude : 180^o 09' 29.0"S
Longitude : 178^o 26' 43.2"E

Notes on seaward edge: (ie eroding, accreting with seedlings? Stable sediment, few young seedlings offshore
Remarks (include names of observers/team):
George Petro (Vanuatu), Joanne Pita (Solomon Islands), Katareti (Kiribati), Champion Mata'u (American Samoa), Thomas Bebeu (Solomon Islands), Marciano Imar (Pohnpei), Ana Tiraa (SPREP).

Mangrove Monitoring Field Data Sheet

Date : _16.03.07_ Time: _0948_ Site name: R.T. Kamarusi Park, Suva, Fiji
Transect number: _2_____ Vegetation zone (dominant tree species): R. stylosa, some R. mangle

Transect landward start Latitude :18^{o} 09' 27.69"S.
Longitude : 178^{o} 26' 39.44"E

Description

Compass heading 90 degrees from coastline: 120^{o}

Zone	Species present	Width (m)	Degree of Impact	Impact type
1	Bruguiera, Rhizophora mangle, Excoecaria agallocha	25.7	Moderate	cuttings
2	Bruguiera gymnorrhiza	4.5	Highly impacted	Bark stripping, garbage, hydrocarbons
3	R. mangle. R. stylosa	26.9	Slightly impacted	Cutting, garbage

Transect seaward end Latitude : 180^{o} 09' 29.85"S
Longitude : 178^{o} 26' 42.22"E

Notes on seaward edge: (ie eroding, accreting with seedlings? Stable sediment, very few seedlings, seaward edge Rhizophora trees roots not fixing into sediment

Remarks (include names of observers/team):

Robert Kinika (Solomon Islands; Rufus Mahuro (PNG), Deyna marsh (Cook Islands), Susan Ewen (PNG), Selaina Vaitautolu- Tuimavave (American Samoa).

Highly impacted zone 2 at Kamarusi Park, note stripped bark and light gaps in canopy

Moderately impacted zone 3 at Kamarusi Park, seaward edge roots are not fixing in the mud because of large woody debris rolling around at high tide.

Example 2: Tongatapu, Tonga

During the AusAID Tonga Environment and Planning Project, Ministry of Environment staff were trained how to carry out a level 1 baseline survey of mangrove species zones. Between March and September 1998 Ministry staff undertook 45 mangrove survey transects at 20 mangrove locations in the Fanga ‘Uta and Fanga Kakau lagoons (see map).

These data were reviewed by the author, and summarized into the below Table 6. The Impact Code levels used are defined in Table 4, and the impact types are defined in Table 5.

Aerial view of Halaleva mangrove margin, Tongatapu

Aerial view of Nukuhetulu mangrove forest, Tongatapu

Map of Fanga' Uta lagoon, Tongatapu, Tonga showing location of mangrove survey sites.

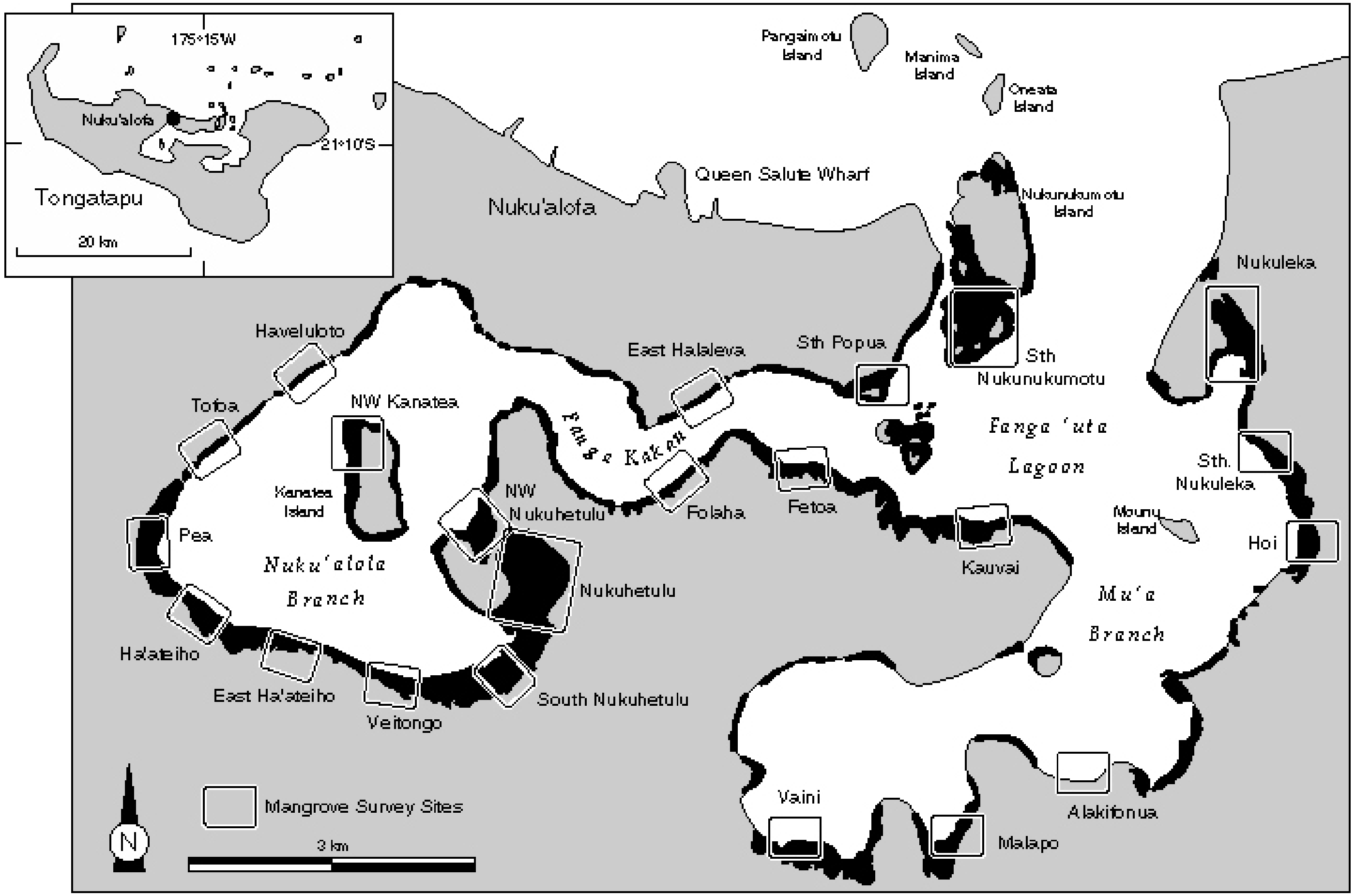


Table 6. Summary of Mangrove Level 1 Survey Data, 1998.

Transect Number	**Village**	**Distance (m)**	**Species**	**Impact code**	**Impact type**
0001	Tofoa (1)	0 15	Bare Rm	5 3	CO, IC, OT CO, IC, OT
0002	Tofoa (2)	0 36	Mixed, Rm Rm	2 2	CO, IC CO, IC
0003	Havelulotu (1)	0 8	Ea Rm	5 5	BU, IC BU
0004	Havelulotu (2)	0 12.5-19 19-25	Grass Rm, Ea Rm	5 5 5	IC IC IC
0005	Havelulotu (3)	3-8 8-18	Ea Rm	4 4	IC IC
0006	Hoi (1)	0-41 41-83 83-211	Rm, Rs Rm, Rs Rm	2 3 3	IC IC IC
0007	Hoi (2)	0-87	Rm, Rs	2	CO, ER, IC, MU, OT
0008	Hoi (3)	0-20	Rm	3	CO, ER, IC, MU, OT
0009	‘Alakifonua (1)	0-150	Rm, Rs	4	ER, IC
0010	‘Alakifonua (2)	0-32 32-45	Mixed Rs, Rm	3-4 3-4	ER, IC ER, IC
0011	‘Alakifonua (3)	0-10 10-45	Mixed Rm	1 1	ER, IC ER, IC
0012	Malapo	0-18 18-38 38-58 58-114 114-267	Mixed Rm Rm Rm Rm	2 1 2 1 4	ER IC
0013	Vaini	0-10 10-160 160-190	Rm Rm Rm	5 3 2	IC, DU IC IC
0014	E. Ha’ateiho(1)	0-28 28-34 34-64 64-94 94-106 106-140	Bare L Bg, L, Rm Mixed Mixed Rm	5 4 4 4 3 3	IC IC IC IC IC
0015	E. Ha’ateiho (2)	0-21 20-63 63-71 71-127	Bare Rm Bare mixed	5 4 5 4	IC, CO DU IC, sewage

Table 6. (continued)

Transect Number	**Village**	**Distance (m)**	**Species**	**Impact code**	**Impact type**
0016	Ha'ateiho (1)	0-60 60-90 90-112	Bare Rm Rm	5 5 5	IC, DU IC, MU IC, MU
0017	Ha'ateiho (2)	0-22 22-52 52-112 112-129	Bare Rm Rm Rm, Rs	5 4 3 2	MU, IC MU, IC IC IC
0018	E. Halaleva (1)	0-30	Mixed	5	CO, oil, DU
0019	E. Halaleva (2)	0-11 11-18 18-33	Hibiscus Ea Rs, Rm	4 4 4	IC
0020	Veitongo (1)	0-22 22-60 60-78 78-106	Mixed Mixed Mixed Rm	5 5 5 4	IC, BS, DU CO IC
0021	Veitongo (2)	0-15 17-52	Mixed Rm	4 4	DU IC
0022	South Popua (1)	0-60 60-85	Mixed Rm	5 5	DU, IC IC
0023	South Popua (2)	0-30 30-120	Mixed Rm	5 4	DU, IC CO, IC, DU
0024	South Popua (3)	n.d n.d-12 12-96	Ea Bare Rm	5 5 5	IC IC IC
0025	Kauvai (1)	0-9 9-75 75-64	Ea, mixed Rm Rs	3 4 4	IC IC IC
0026	Kauvai (2)	0-68	Rm	4	IC
0027	Fetoa (1)	0-78 78-103	Mixed Rm	3 3	IC DU, IC
0028	Fetoa (2)	0-9 9-86	Bare Rm	5 4	IC IC
0029	Folaha (1)	0-55	Rm	3	IC
0030	Folaha (2)	0-72	Rm	3	IC
0031	NW Nukuhetulu	0-540 540-547	Mixed Rm	4 3	DU IC
0032	S. Nukuleka (1)	0-16	Rm	3	IC

Table 6. (continued)

Transect Number	**Village**	**Distance (m)**	**Species**	**Impact code**	**Impact type**
0033	S. Nukuleka (2)	0-57	Rm	3	IC, ER
0034	S. Nukuleka (3)	0-37	Rm	4	IC, ER
0035	Nukuleka (1)	0-8 8-70	Mixed, bare Rm	5 2	IC, ER IC
0038	Nukuleka (2)	0-9	Rm	4	IC, ER
0039	NW Kanatea (1)	0-40	Rm	5	IC, pollution
0040	NW Kanatea (2)	0-15 15-28	Mixed Rm	4 3	DU, IC, pollution BS
0041	S. Nukuhetulu	0-30 30-188 188-203	Mixed, Bg Mixed Rm	2-3 5? 5?	IC, BS IC, BS
0042	S. Nukuhetulu	0-227 227-251	Mixed Rm	2 2	IC, BS
0043	S. Nukunukumotu (1)	0-360 360-600 600-840 840-1287	Rs Rs Rm Rs	2 3 2 2	IC IC IC
0044	S. Nukunukumotu (2)	0-120 120-330 330-401 401-581 581-640 640-880 880-1135	Mixed, Rs Mixed Rm Rs Mixed L Mixed	3 3 3 3 5 3	IC IC IC IC
0045	S. Nukunukumotu (3)	0-248 248-696	Mixed Rs	3 3	IC

Key to species

Rm = *Rhizophora mangle* (Tongolei)
Rs = *Rhizophora stylosa* (Tongolei)
Bg = *Bruguiera gymnorrhiza* (Tongo ta'ane)
L = *Lumnitzera littorea* (Hangale)
Ea = *Excoecaria agallocha* (Feta 'anu)

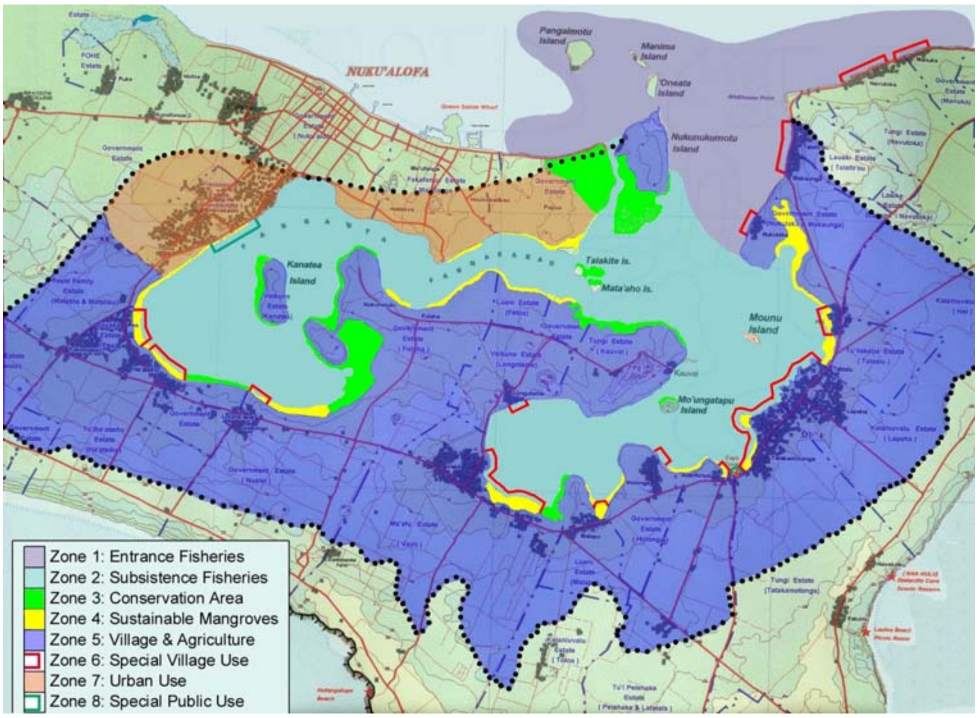
Comments on the Tongatapu data

The transects were located perpendicular to the shoreline through the mangrove ecosystem at all of the major mangrove areas on the Fanga 'Uta lagoon. The surveys indicate that zonation is simple and marked, with different species assemblages forming zones parallel to the shoreline from the lagoon fringe to the edge of dry land. The lowest zone (to seaward) consists of *Rhizophora mangle* and/ or *R. stylosa*. Landwards of the *Rhizophora* zone is a *Bruguiera gymnorrhiza* zone, with occasional *Lumnitzera littorea*. The *Bruguiera* zone becomes interdispersed with *Excoecaria agallocha* towards land.

The transect data show that there is overall high human impact on the mangroves of the Fanga 'Uta lagoon. Locations with higher level of human impact, requiring rehabilitation, were shown to be Havelutotu, East Ha'ateiho, Ha'ateiho, East Halaleva, Veitongo, Alakifonua and South Popua. Most common impacts are cutting of trees, dumping of garbage, and reclamation for construction of houses. House construction usually introduces problems of sewage disposal.

Areas shown by the Baseline Survey Transects (Table 6) to have more moderate human impact were Malapo, South Nukuhetulu and South Nukunukumotu. These are larger and more inacessible mangrove areas (see map).

This data was later used to zone mangroves of the area into different classes of usage: Special Village Use, Sustainable Mangroves, and Conservation Areas (map below from Prescott et al., 1993?).



<u>Mangrove zones developed as part of the Fanga 'Uta Lagoon Environmental Management Plan Prescott et al., 1993?),</u>

Example 3: Ailuk Atoll, Marshall Islands.

In January 2007 in consultation with the Ailuk Atoll Marine Resource Management Advisory Committee mangrove resources of the atoll were baseline surveyed using level 2 monitoring procedures.

Table 7. Mangrove tree dimensions at Bigen Mangrove Pond.

Tree ID number	Diameter (cm)	Height (m)
882	30.2	3.4
888	22.1	3.6
880	31.4	3.4
874	23.1	3.7
875	11.2	2.5
876	9.1	3.2
877	16.3	3.2
881	19.5	3.2
868	19.9	3.4
892	15.9	3.1
886	38.8	3.9
867	12.8	3.9
879	12.4	2.0
889	18.8	4.3

Mangrove pond on Bigen Islet, Ailuk atoll.

Table 8. Mangrove sapling dimensions at Bigen Mangrove Pond.

Sapling ID number	Diameter (cm)	Height (m)
887	1.5	1.9
890	1.3	1.3
893	1.3	2.2
884	1.8	2.5
873	1.8	1.7
888	1.1	1.3
866	1.3	1.2
869	1.3	1.2
885	1.3	1.3
896	1.7	1.7
899	1.3	1.6
871	1.1	1.8
907	1.1	1.6
878	1.3	1.9
865	1.4	1.9
898	1.2	1.7
894	1.4	2.4
897	1.0	1.5
872	1.0	1.8

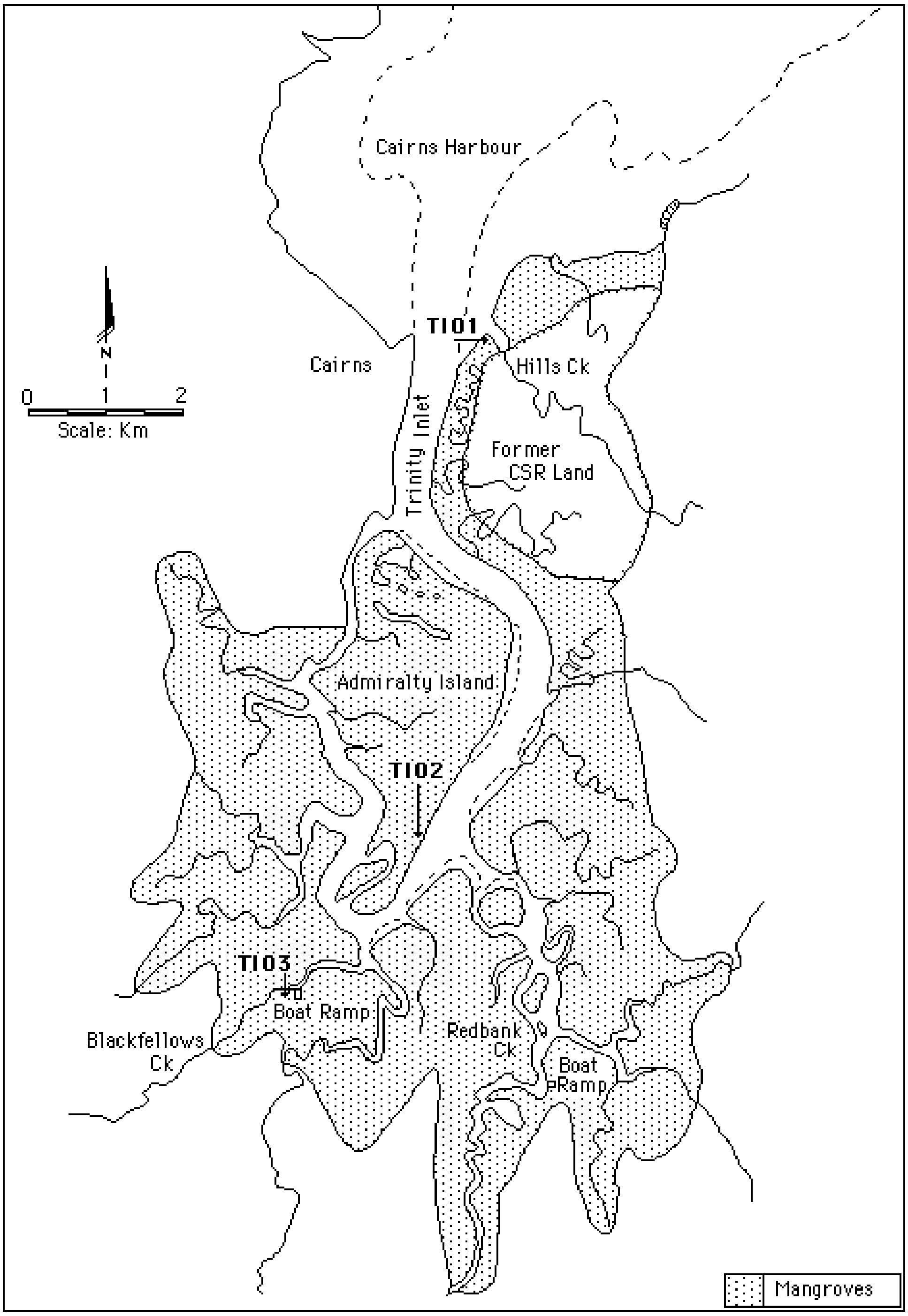
Comments on the Ailuk data:

Mangrove resources of Ailuk atoll were surveyed, finding one small inland area in Bigen islet with *Bruguiera gymnorrhiza* trees, which was established as a permanent monitoring site. This mangrove area found at Bigen, the fourth island from the north on the eastern string of islands along the Ailuk windward reef, was the only remaining mangrove area known on Ailuk Atoll. It is located in an inland depression on the NE side of the island (10^{o} 25’ 31.6” N; 169^{o} 58’ 01.0”E).

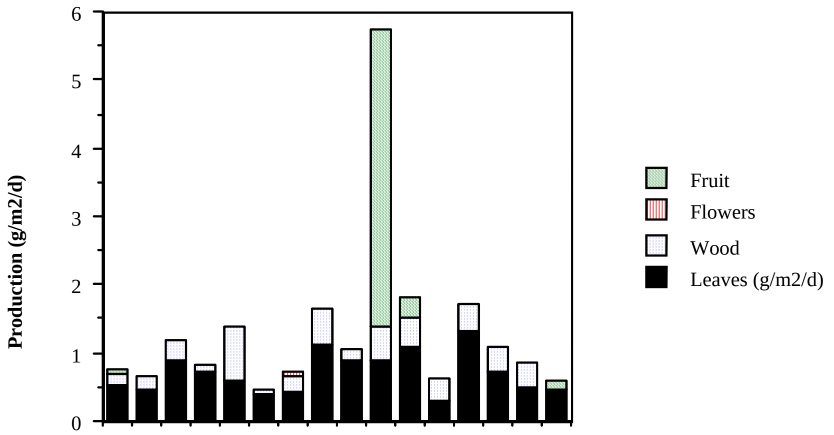
The site appeared to be natural, with dense mangrove growth. The mangrove surface in the larger depression was surveyed to be 1.71 m above MSL. The mud substrate was found to be alkaline, with a pH of 8.5-9.0. Fosberg (1975) thought the mangrove mud of these depressions to be acid, however numerous tests during the present study found all such situations to be alkaline. The water present at Bigen mangrove pond was fairly saline, with an average salinity of 32.3 mS/cm, and conductivity of 20.1 ppt.

Mangrove species present were all *Bruguiera gymnorrhiza*, in several size classes (Tables 7 and 8). There were 14 mature trees with an average diameter of 20.1 cm, and an average height of 3.3 m. These at the time of sampling (January) carried propagules which were not mature for abscission. There were also 19 saplings all in the larger triangular pond, with an average diameter of 1.3 cm and an average height of 1.7 m. These were densely spaced. Under both the trees and saplings were a large number of seedlings of mainly less than 3 years of age, and less then 60 cm in height, in total over 150 individuals densely spaced.

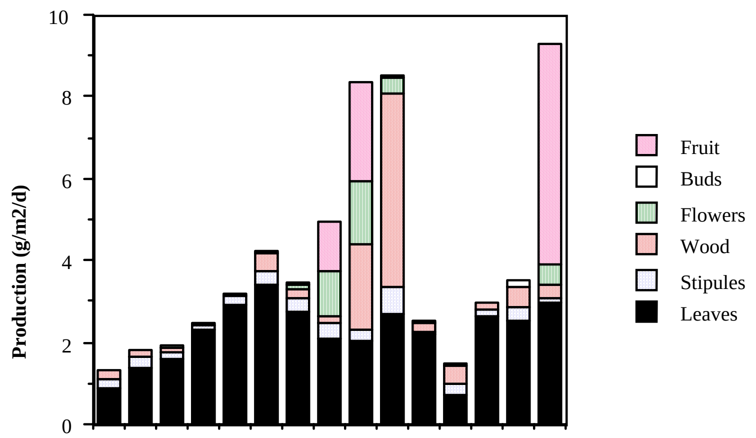
Example 4: Litter productivity at Trinity Inlet mangrove swamp, Cairns, Queensland.

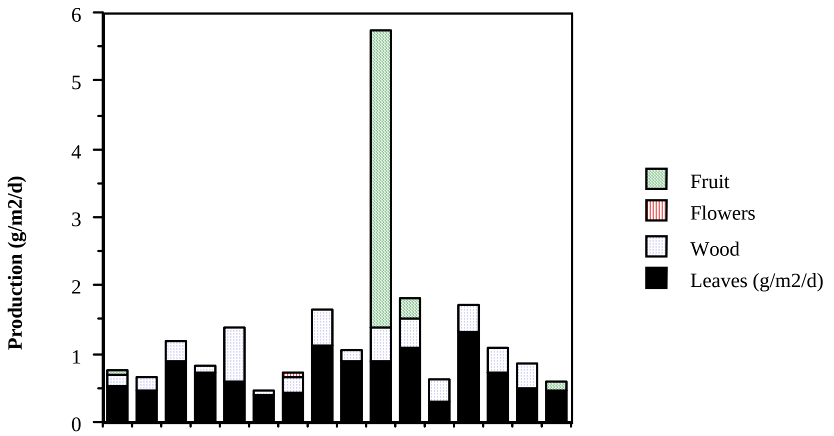


<u>Map showing the Trinity Inlet mangrove swamp, and permanent plots located in an approximate line through the centre</u>

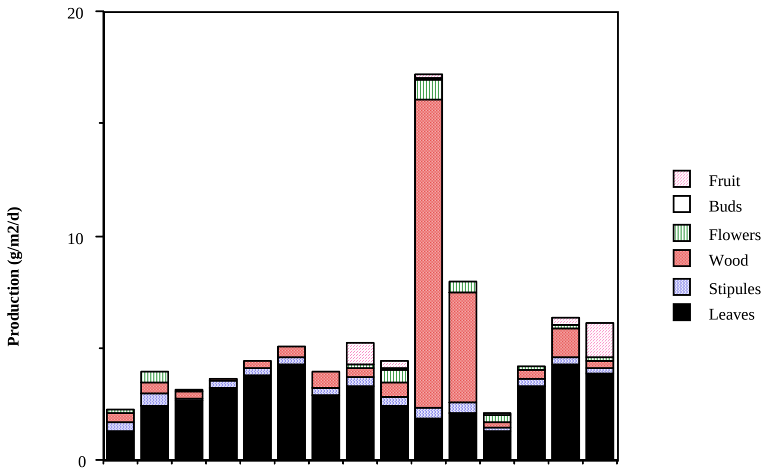


<u>Graph showing productivity at the seaward plot TI01 from May 1994 to February 2006.</u>

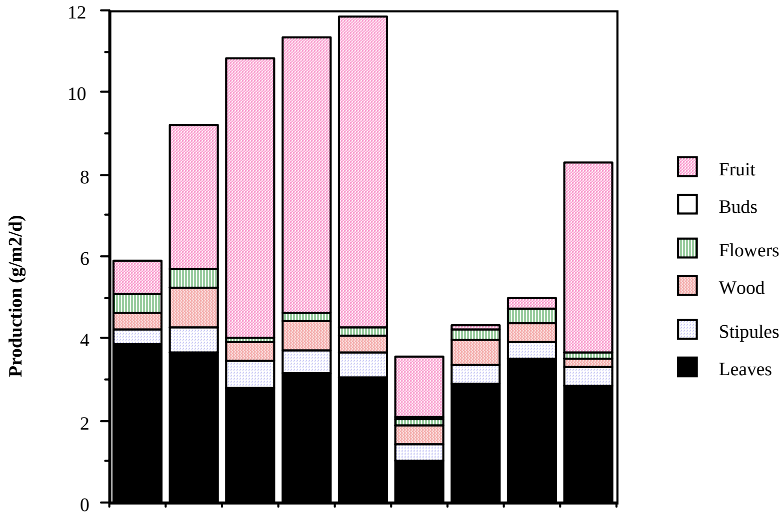




<u>Graph showing *Rhizophora* productivity at the centre plot TI02 May 1994-February 2006.</u>



Graph showing *Bruguiera* productivity at the centre plot TI02 May 1994-February 2006.



Graph showing productivity at the landward plot TI03 May 1994-February 2006.

Comments on the Trinity Inlet data:

Production at the seaward plot TI01 was predominantly from *Avicennia marina*. Production graphed above from 20 May 94 to 16 Feb 96 shows *Avicennia* fruiting in April, showing a sudden event with little range in time. Leaf production was higher in the period January to May, and also higher in July both years.

The second graph shows *Rhizophora stylosa* production at the central Admiralty Island plot TI02 from 20 May 94 to 16 Feb 96. This shows both flowering and fruiting in the period January to February. Leaf production was higher October to April, with a maximum of 4.5 g m^{-2} d^{-1} in November, reducing in late summer during the reproduction period. Leaf production reached a minimum of <1 g m^{-2} d^{-1} during the winter in July and August. Wood production was higher in the months of March and April than other months of the year.

The third graph shows *Bruguiera gymnorrhiza* production at the central TI02 plot . Flowers were produced in the period January to May, but most mature fruits were dropped in January. Leaf production was higher in the period August to January, of around 4 g m^{-2} d^{-1} , reducing in late summer during the reproduction period. Leaf production was lowest at 1-2 g m^{-2} d^{-1} in May and June. Stipule production reached a maximum during March to May.

The last graph shows production at the landward TI03 site. This is largely from *Rhizophora*. Leaf production is higher during the summer period of January to February at 4 g m^{-2} d^{-1} , falling during late summer during reproduction, and reaching a minimum of 1 g m^{-2} d^{-1} during the winter in June and July. Flowers were produced through most of the year, but with a maximum during the months of January to May. There was high productivity from this site particularly in fruiting, and low wood production relative to other sites, probably reflecting its more sheltered location.

Annual Production

The total annual production of litter from the Trinity Inlet sites is given in Table 9.

Table 9: Annual production of mangrove litter in Trinity Inlet.

SITE	PERIOD	ANNUAL PRODUCTION (g dry wt m^{-2})
TI01	20/5/94-20/5/95	505
TI02 *Rhizophora*	20/5/94-20/5/95	1385
TI02 *Bruguiera*	20/5/94-20/5/95	2020
TI03	1/12/94-1/12/95	2532

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